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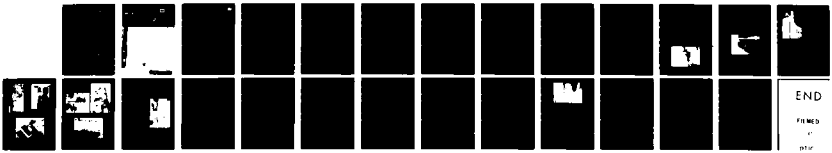

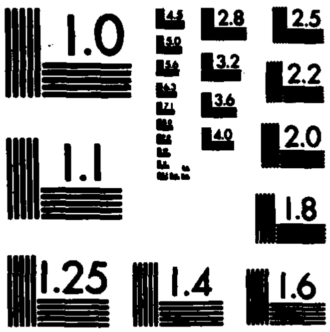

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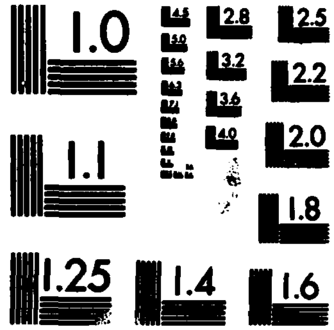

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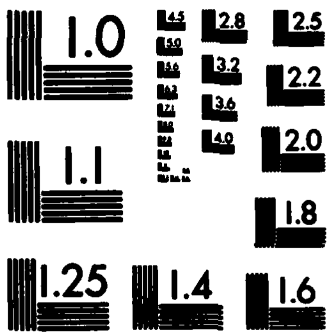

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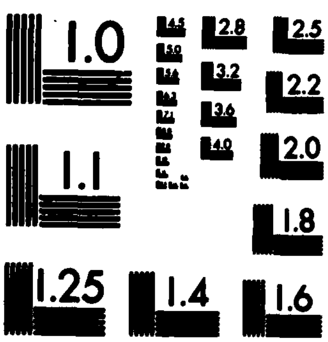

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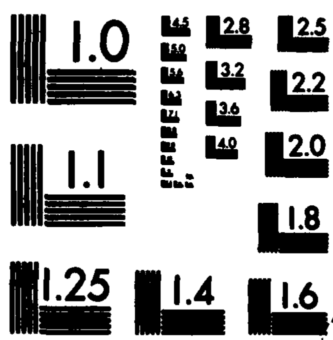

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Direct filtration of streamborne glacial silt

CRREL Report 82-23

September 1982

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Michael D. Ross, Richard A. Lowman and Robert S. Sletten

Prepared for
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A direct filtration, water treatment pilot plant was operated on the Kenai River at Soldotna, Alaska, during the summer of 1980. The purpose of the pilot plant operations was to determine the feasibility of the direct filtration process for removal of glacial silt. The major criterion used to determine feasibility was production of water containing less than 1.0 NTU of turbidity. For the range of raw water turbidities encountered (22-34 NTU), the pilot plant testing indicated that direct filtration was feasible and could be considered as an alternative to conventional water treatment plants containing sedimentation tanks.

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PREFACE

This report was prepared by Michael D. Ross, Project Engineer, and Richard A. Lowman, Principal Investigator, both of Trans-Alaska Engineering, Seward, Alaska, and Robert S. Sletten, Environmental Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The project was conducted under DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions,* Task D(04), *Cold Regions Design and Construction,* Work Unit 16, *Water Supply in Cold Regions.*

The report was technically reviewed by C.J. Martel and S.C. Reed of CRREL, and by W. Persich of Collins, Ryder and Watkins, Inc. of Tacoma, Washington. We appreciate their comments. We also thank V. Gehrke of Soldotna, Alaska, for permission to construct the pilot plant on his property and for his generous donation of tools and experience during pilot plant construction.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
foot	0.3048*	metre
$foot^3$/second	0.02831685	$metre^3$/second
gallon (U.S. liquid)	3.785412	litre
gallon/$foot^2$	40.74584	litre/$metre^2$
inch	25.4*	millimetre
mile	1.6093	kilometre
pound/$inch^2$	703.0696	kilogram/$metre^2$

*Exact.

DIRECT FILTRATION OF STREAMBORNE GLACIAL SILT

Michael D. Ross, Richard A. Lowman
and Robert S. Sletten

INTRODUCTION

Rapid population growth in Alaska, particularly on the Kenai peninsula, is placing increasingly heavy demands on existing water sources. Recent studies indicate that presently used groundwater sources may not be sufficient to meet expected demands, and that surface water may have to be used. Industrial activity in the North Kenai–Soldotna–Kenai area, for example, may exceed the groundwater aquifer capacity within five years (Trans-Alaska Engineering/URS 1979). Surface water, particularly south of the Alaska Range, represents a significant water resource in Alaska. Many of the streams and rivers in this area of Alaska, however, are fed by glaciers and would require treatment prior to domestic use to remove the glacial silt, which imparts the characteristic milky or steel gray color to the water. Depending on the time of year, glacial silt concentrations can range from 1 to over 150 mg/L. Although the treatability of non-glacial streams can be readily established, little was known about the treatability of glacial streams. This study was conducted to determine the treatability of a glacier-fed stream by direct filtration for the production of potable water.

Glacial characteristics

Most of the data collected on glaciers in Alaska has been in central Alaska, south of the Alaska Range (Guymon 1974). Glaciers cover about 17,000 square miles of Alaska and predominate in the wet and cool coastal mountain ranges. Fine rock silt (glacial flour) is found in layers in the lower part of most glaciers. The apparent source of rock silt is the glacier bed, with rock being ground to fine particles and transported by melting and freezing cycles at the bed/glacier interface. The layers of heavy silt concentration (usually a few centimeters thick) vary a great deal in ice concentration, from 10 to 85% by volume (Boulton 1970).

Glaciers usually increase in size during the winter and decrease during the melt season. Approximately 95% of the total silt load from a glacier will occur during the summer months, although sediment delivery rates are extremely variable from glacier to glacier and year to year (Guymon 1974). This variability is reasonable, considering the mechanism of silt formation and the variation in seasonal patterns that can occur.

Two characteristics of glaciers appear to be significant when considering using glacier-fed streams for water supplies: the highly variable sediment release and the well-defined melt season. If a glacial stream is selected as a water source, attempts should be made to establish the limits of variability of sediment release before a treatment process is selected. If the upper limit for sediment release cannot be established, then treatment should include provisions for seasonally heavy silt removal. This is a conservative approach to selecting a process and may not be necessary if the upper limit for sediment release could be reasonably established or if the selected process can be proven to remove glacial silt under conditions actually encountered at a given site. Because the melt season is well defined and almost all of the glacial silt is released during the melt season, this is an optimum time to test a process at pilot scale to determine whether it is capable of removing glacial silt. This approach should account for the known stream quality and the characteristics of the process to be tested. The results of the testing will indicate if the process can be used for water containing glacial silt.

Water treatment

The objective of municipal water treatment is to provide a potable supply, that is, one that is chemically and bacteriologically safe for human consumption. Treated water must also be aesthetically acceptable—free from apparent turbidity, color, and objectionable tastes and odors. Common sources for municipal supplies are wells, lakes, rivers and reservoirs. Well supplies normally yield cool, uncontaminated water that is of uniform quality and is easily processed for municipal use. Surface water is much more variable in quality and is subject to pollution, both man-made and natural.

The primary process in surface water treatment is chemical clarification by coagulation, sedimentation and filtration. River supplies normally require extensive treatment facilities with great operational flexibility to handle the day-to-day variations in raw water quality. As illustrated in Figure 1, river water treatment plants usually consist of presedimentation basins, chemical coagulation basins, settling tanks and filters. The primary sources of waste from the water treatment process are sludge from the settling tanks and wash water from backwashing the filters.

Direct filtration has been defined as "a treatment system that is not preceded by sedimentation" (Culp 1977). The advantage of removing all the particulates directly on the filter instead of removing part of them by sedimentation is a capital cost savings of 20–30% for treatment works and an operation savings of 10–30% for chemicals (Logsdon 1978). An additional advantage is that less sludge is produced than with a sedimentation/filtration system. The disadvantages of direct filtration are shorter filter runs and practical raw water quality limits that restrict the application of the process. An effect of reduced filter runs is an increased requirement for backwashing; the cost of this is usually not significant when compared to the savings in capital cost, but the ability to operate filters becomes difficult with short filter runs (Culp 1977).

MATERIALS AND METHODS

Experimental design

To test the feasibility of using a direct filtration water treatment plant for producing potable water from a glacier-fed stream, a pilot plant was constructed on the Kenai River in Soldotna, Alaska (Fig. 2). The pilot plant was constructed to duplicate on a small scale the major unit processes in a full-scale treatment plant (Fig. 1), with these exceptions: 1) the presedimentation basin shown in Figure 1 was replaced by a hydrocyclone, a device that uses centrifugal force to separate coarse solids from liquid, and 2) there were no provisions for settling tanks or the addition of activated carbon, chlorine and fluorine. A schematic of the pilot plant is presented in Figure 3. The pilot plant operated between 10 June and 19 August 1980, with data obtained for 38 filter runs. A filter run is defined here as the time from the start of filtration until the breakthrough of water containing greater than 1.0 Nesseler Turbidity Unit (NTU). No attempt was made to modify the natural water characteristics of the Kenai River during the period the pilot plant operated, since the intent of the study was to determine if potable water could be produced during the time the stream was carrying a glacial silt

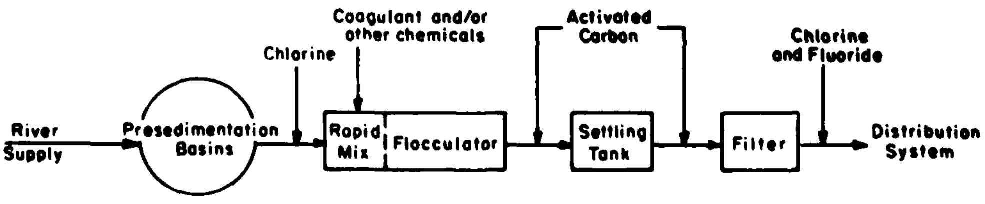


Figure 1. Schematic of typical surface-water treatment system. (After Hammer 1975.)

load. Loading on the filters varied from 2 to 7.5 gal/min•ft², and water was sampled as it entered the plant, after it passed through the hydrocyclone, and as it left the plant. The filtered water was returned to the river and the filters were backwashed with local well water. The pilot plant facilities were housed in a wood frame shelter sheeted with translucent fiberglass (Fig. 4). The pilot plant design criteria are summarized in Table 1, and a detailed description of plant facilities and operations follows.

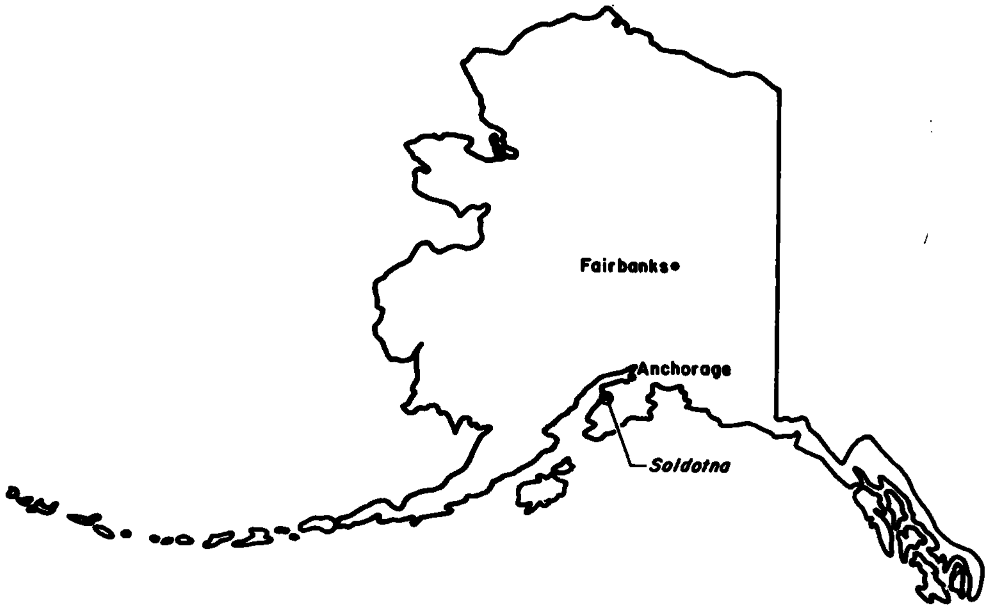


Figure 2. Location of the pilot plant.

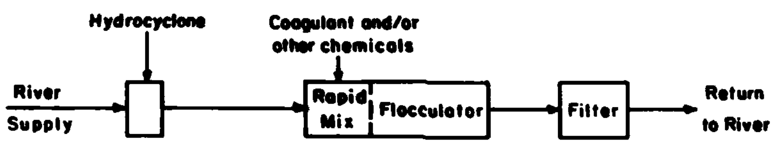


Figure 3. Schematic of direct filtration pilot plant.

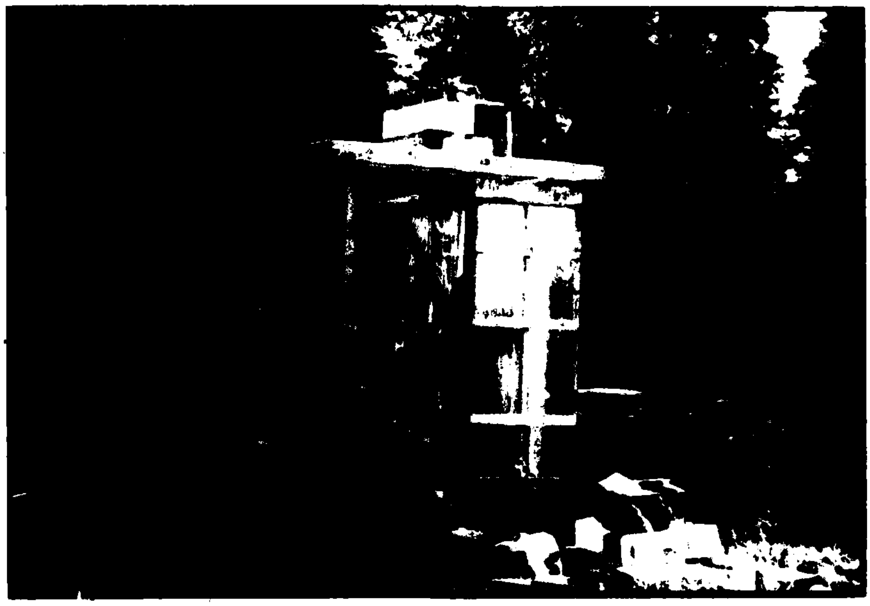


Figure 4. Pilot plant building.

Table 1. Design criteria for the pilot plant.

	Criteria
Maximum flow rate	2.0 gal/min
Rapid mixing detention period (2.0 gal/min)	30 s
Flocculation	
Number of units	3
Dimensions	16×15×12 in.
Floc period (2.0 gal/min)	15 min
Filtration	
Number of units	2
Filtration rate	2-8 gal/min·ft²
Filter media depth	30 in.
Available head	100 in.
Backwash rate	26 gal/min·ft²
Chemical dosage rates	
Alum	5–20 mg/L
Lime	5–10 mg/L
Coagulant aid (polyelectrolyte)	0.25–0.50 mg/L
Filter aid (polyelectrolyte)	0.10 mg/L

Figure 5. Intake piping (arrow) for pilot plant where it comes ashore.

Pilot plant intake

The pilot plant drew water through an intake approximately 5 feet from the outside edge of a large bend in the Kenai River (Fig. 5). The intake was approximately 4 inches above the river bed, which consisted of hard gravel. During the course of testing the submergence of the intake varied from 2.5 to 5 feet. The river velocity past the intake was approximately 2 ft/s.

Hydrocyclone

A Krebs Engineering Model W2U Desander was used as the pilot plant hydrocyclone (Fig. 6). It operated at an 8.4-lb/in² headloss, with a flow

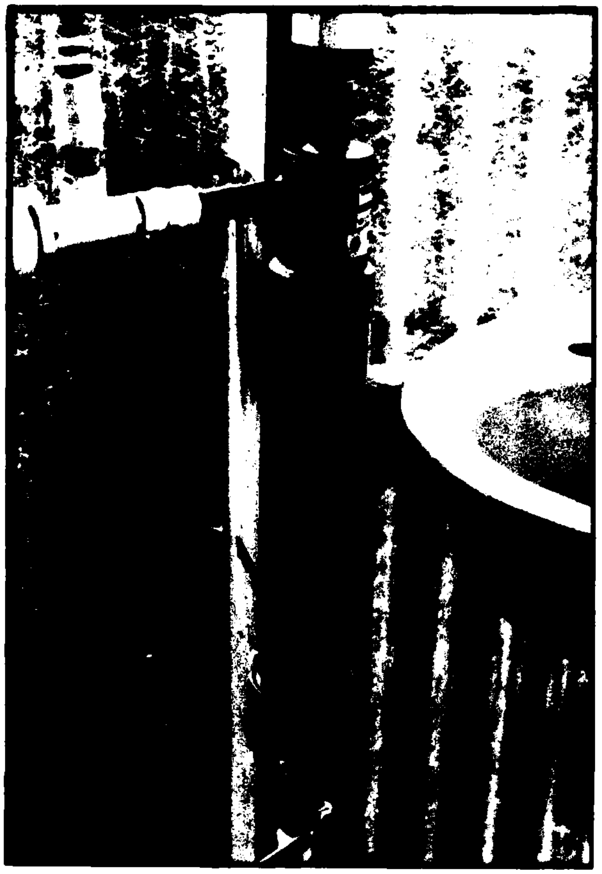


Figure 6. Hydrocyclone installation.

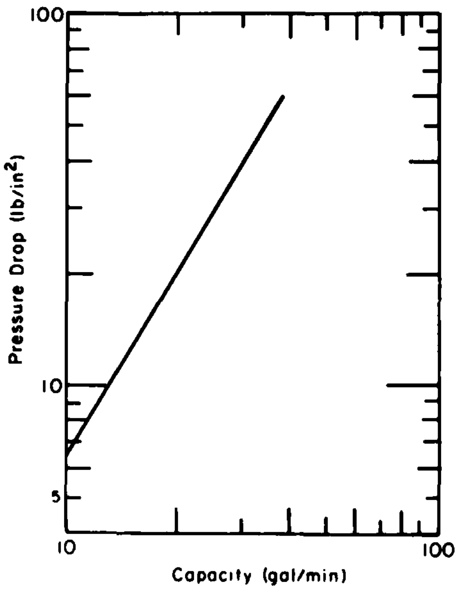


Figure 7. Capacity vs pressure drop in the hydrocyclone.

of approximately 12 gal/min (Fig. 7). The hydrocyclone was manually purged of accumulated sand every 2–4 hours.

Chemical addition system

The pilot plant chemical addition system consisted of chemical feed solutions pumped via chemical metering pumps (Precision Control Products Model 11311) from plastic storage containers to the rapid mixing unit and the flocculator basins (Fig. 8). The design of the rapid mixing unit was based on a detention time of 30 seconds at a maximum flow through the flocculator of 2.0 gal/min. The unit was constructed adjacent to the flocculator and consisted of an unbaffled rectangular compartment 4.38 inches square and 12 inches deep, with a volume of 0.13 ft^3. All plumbing in the pilot plant was constructed of PVC pipe.

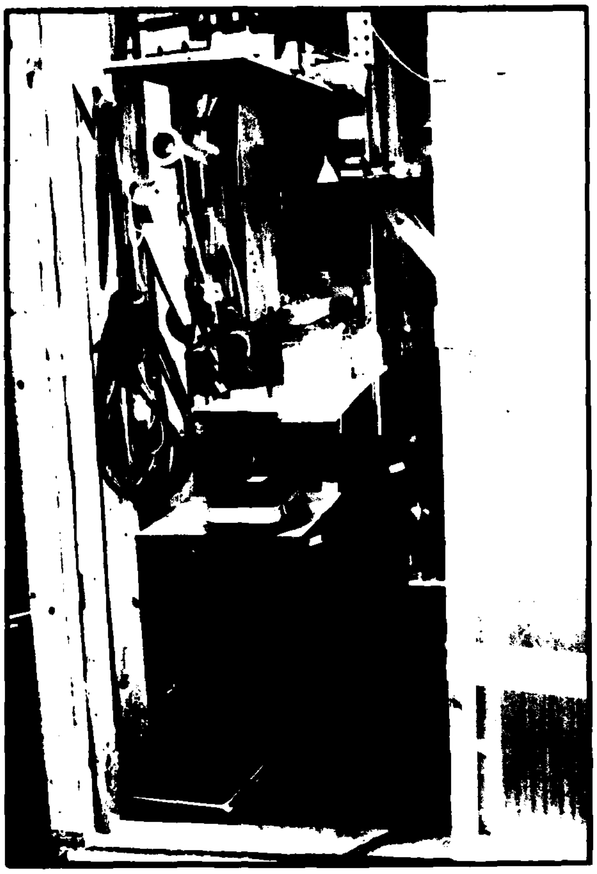
During most of the study, rapid mixing was provided by a 1/40-horsepower motor spinning a 1.5-inches-diameter, 3-blade propeller at 1500 rpm. This combination produced an estimated mixing energy gradient (G) of 260 s^{-1}. As the study progressed, it became necessary to add a water cooling coil to the motor to allow it to operate continuously. Two additional blades were later mounted on the propeller shaft, one directly above and one below the raw water inlet, to provide upward and downward thrust. This arrangement provided very turbulent mixing, with G estimated at 1000 s^{-1}.

Flocculation system

The tapered flocculation unit was a clear acrylic chamber, separated by baffles into a three-compartment flocculator (Fig. 9). The dimensions of the compartments (16 × 15 × 12 inches) were chosen to allow a flow of 2.0 gal/min at a detention time of 5 minutes per compartment.

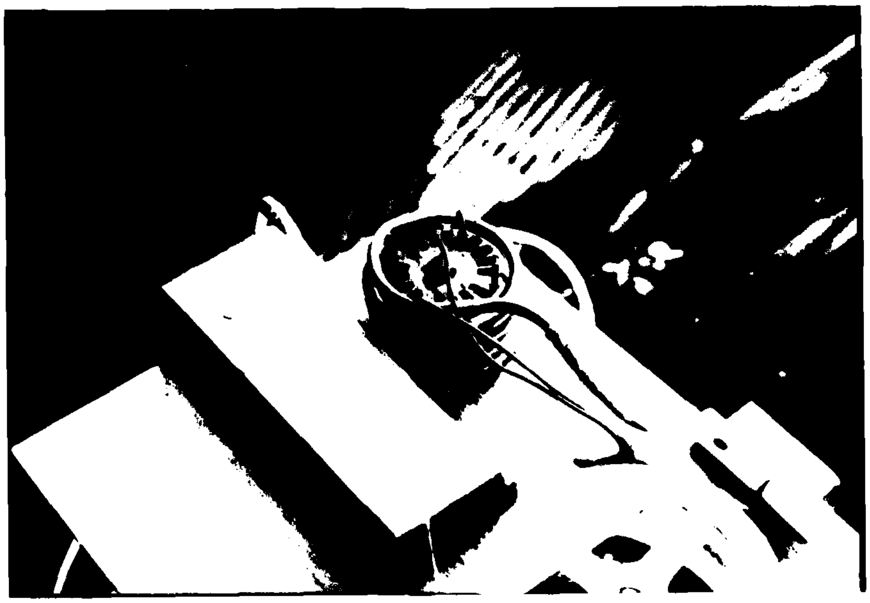
A variable-speed motor and paddle assembly was installed for each compartment, allowing the mixing energy to differ in each compartment. The entrance and exit pipes on this unit and subsequent process units were sized to ensure an average velocity of less than 1 ft/s to minimize floc shear.

Flat-bladed paddles were used for flocculation, with the first two compartments having two sets of paddles each and the third having one. Each rectangular paddle measured 2.0 × 8.0 inches. The paddles had surface areas approximately equal to 20% of the cross-sectional area of the water surface in the flocculating compartments. The third compartment had only one set of pad-



a Metering pumps on bench above storage containers

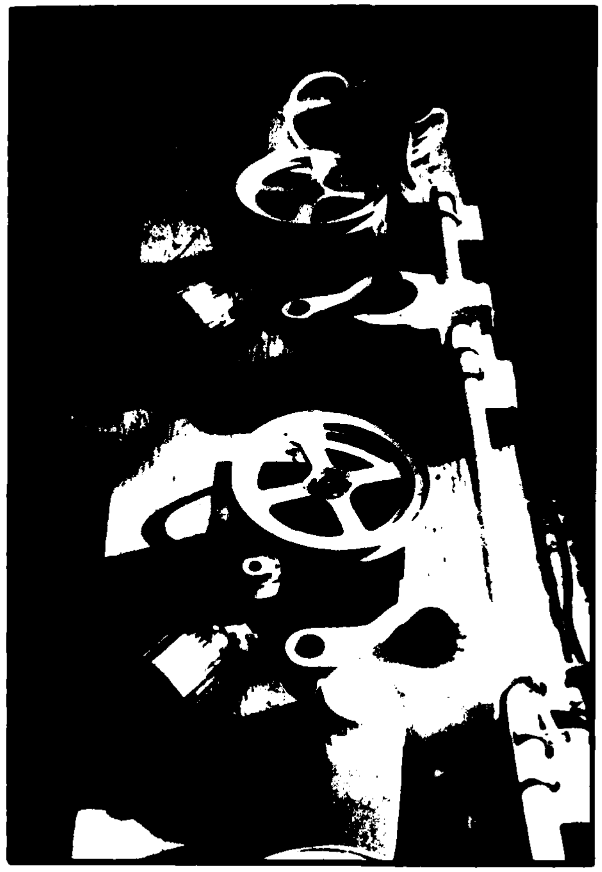
b Turbulence in rapid mixing unit



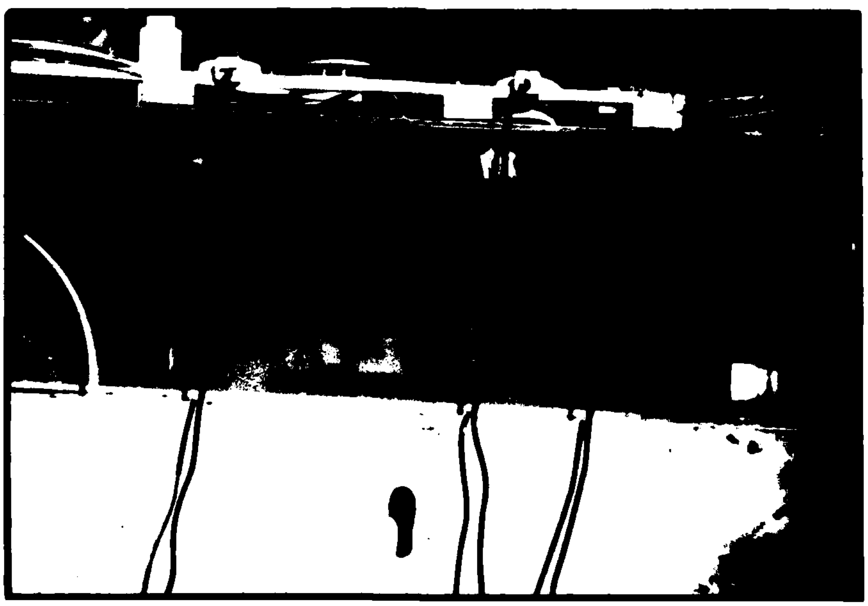
c Cooling coil on rapid mixing unit

Figure 8 Chemical addition system

a. Flocculator mounted on treatment building.



b. Mixing motors, rheostats and pulleys.



c. Close-up of flocculator showing pulleys and paddles.

Figure 9. Flocculation system.

dles because of the low degree of mixing energy desired in that compartment.

Filtration system

The two gravity filter columns were obtained from Neptune Microfloc, Inc. Each column consisted of 30 inches of filter media in a 4.5-inch-i.d. acrylic pipe (Fig. 10). Table 2 shows the types and depths of the media. A constant hydraulic head of approximately 8.0 feet was maintained by an overhead feed manifold. Excess flows were drained via an overflow pipe.

Filter flow rates were individually controlled with effluent pressure regulators; the flows were measured with rotameters. The pressure differential (head loss) across the filter media was measured with a differential pressure gauge. Filter application rates varied from 1.0 to approximately 9 gal/min•ft².

The filters were cleaned by backwashing and surface washing the media. No provisions for air scouring were provided and this was not attempted. The backwash flowed from a nearby well at 2.9 gal/min. This rate expanded the bed by 50%. The backwash water volumes were calculated by measuring the backwash flow rate with the media fluidized and measuring the time required to produce a visually clean backwash waste.

Pilot plant operations

The pilot was operated continuously and was inspected every 2-4 hours. Before each filter run the chemicals were prepared and the filters were backwashed. The flow to the filters began 30 minutes after the chemical additions were calibrated and the flocculator speeds stabilized. The first 10 gallons into the filters were drained without passing them through the media. The filter effluent sampling was started 1-2 hours after the filters were put on line. The filters were not precoated with filter aids.

Coagulant chemical preparations

Lime, alum, and polymer solutions were prepared at the site. The reagents were weighed to the nearest 0.1 gram on an Ohaus triple beam balance and were diluted with well water. A mechanical mixer was used to ensure that the reagents were completely dissolved. The polymer solutions were mixed for short intervals (less than 30 minutes) to avoid any possibility of molecular shear. The lime and alum solutions were constantly mixed. The chemical feed concentrations ranged from 25 to 5000 mg/L.

Table 2. Filter media in Neptune Microfloc filters*.

Media	*Depth (in.)*	*Effective size (mm)*	*Uniformity coefficient*	*Neptune specification*
Coal	17	1.0-1.1	1.7	MS 4
Sand	9	0.42-0.55	1.8	MS 6
Garnet	4	0.18-0.24	2.0	MS 21

*The actual media in the two columns differed slightly from one another.

Figure 10. Pilot plant filter columns.

The initial chemical doses were estimated from jar test data on glacial waters (Alaska District, Corps of Engineers and Municipality of Anchorage 1979). The jar test is the most widely used method to determine coagulant dosage and flocculation aids in water treatment. The test attempts to simulate the full-scale coagulation-flocculation process used in physical-chemical water treatment plants.

The jar test consists of a series of sample containers, the contents of which can be mixed by individual mechanically operated agitators. The water to be treated is placed in the containers, and the treatment chemicals are added while the contents are being stirred. The contents are stirred rapidly for about one minute to ensure complete dispersion; then the stirring rate is decreased. Flocculation is allowed to continue for a variable period. The stirring is then stopped, the floc is allowed to settle for a selected time, and the results are analyzed for a variety of parameters. Dose rates of the added chemicals are systematically varied to find the combination that gives the best results.

Flow measurement

The flows through the pilot plant were determined by a variety of methods. The raw water flow through the hydrocyclone was determined by measuring its headloss with a mercury manometer. Figure 7 is the manufacturer's headloss-capacity curve.

The flow into the chemical system was measured by a Fisher Porter rotameter. Because algae frequently plugged the rotameter, a bypass line was installed to allow the rotameter to be cleaned without interrupting the process flow.

The chemical solution flows were measured with a graduated cylinder and stopwatch at the point where the solutions entered the flash mixer. The filter effluent flows were individually measured by rotameters and filter backwash rates were measured using a bucket and stopwatch when the media were fully expanded. These flow rates were taken as average values for the entire backwash and surface wash cycles.

Sampling

The pilot plant design (Fig. 3) allowed the following to be sampled: 1) the raw water, 2) the hydrocyclone effluent (the chemical system influent), 3) the hydrocyclone sludge, and 4) the effluent from both filters. In addition, couplings could be opened and samples withdrawn at almost any point in the process.

Most sample taps were allowed to run freely for several minutes before samples were taken. However, the highly concentrated hydrocyclone sludge samples were collected immediately when the sample tap was opened, since the sludge would have rapidly washed out with large quantities of water. A larger hydrocyclone with adequate solids retention could be operated without this scouring and would still produce very concentrated sludge.

RESULTS AND DISCUSSION

Kenai River water quality

Data were obtained from the U.S. Geological Survey for the Kenai River at Soldotna. Provisional data (Fig. 11) indicate that the discharges during pilot plant testing were higher than the 10-year monthly average. As will be seen later in this report, the treatability and quality of the river water declined as flow increased. It is possible that overall water quality was worse than usual during pilot plant testing.

Chemical data for the Kenai River at Soldotna are shown in Table 3. Average values for all parameters except iron indicate that the Kenai River should be an excellent source for domestic water supply. The average value for iron is slightly in excess of the Drinking Water Criterion of 0.3 mg/L, and some action would have to be taken to ensure iron concentrations of less than 0.3 mg/L.

Table 3 indicates that the average suspended solids concentration is 15 mg/L. During the pilot plant study the measured suspended solids averaged 28 mg/L, with a high value of 48 mg/L (Fig. 12). This high value is probably associated with the higher-than-normal discharge of the river and generally lower water quality mentioned earlier.

No background data on turbidity were available, but measured turbidity values during the pilot plant study ranged from 18 to 32 NTU, with an average value of 25 NTU (Fig. 13). As can be seen by comparing Figures 12 and 13, turbidity and suspended solids values do not correlate well. Turbidity is particularly important to this study, since the objective was to demonstrate that direct filtration can produce water containing less than 1 NTU turbidity.

Evaluation of pilot plant testing

The objective of this testing was to determine the feasibility of using direct filtration to remove glacial silt from natural river water. The major criterion used to evaluate the pilot plant performance was the production of water containing less than 1 NTU turbidity. Several other parameters were also evaluated.

Table 4 summarizes the pilot plant filter run data for those filter runs considered successful, i.e. for which water containing less than 1 NTU of turbidity was produced. The initial chemical doses were estimated from jar test data on glacial waters (Alaska District, Corps of Engineers and Municipality of Anchorage 1979). It can be seen that raw water turbidities ranged from 20 to 27 NTU and that several coagulants and combin-

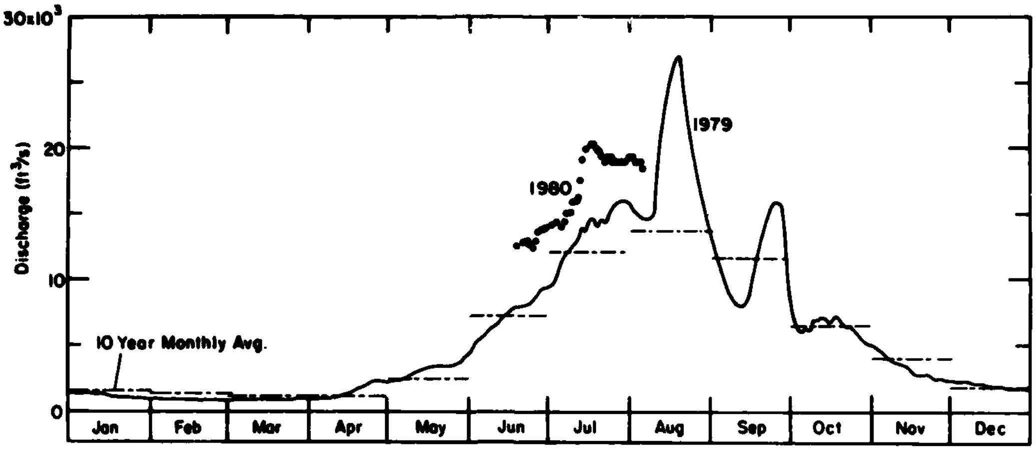


Figure 11. Daily discharge of the Kenai River at Soldotna. The 1980 data are only for the period of pilot plant testing.

Table 3. U.S. Geological Survey chemical data for the Kenai River at Soldotna*.

Parameter†	Reported as	Number of analyses	Average	Standard deviation	Maximum	Minimum
Specific conductance (μmhos)	-	60	70.5	9.28	98	57
pH	-	44	7.16	0.47	8.6	6.1
Alkalinity	$CaCO_3$	45	26.2	3.9	35	15
Nitrate	N	45	0.23	0.28	1.20	0.0
Fluoride	F	44	0.08	0.12	0.1	0.0
Silica	SiO_2	44	4.9	1.4	8.6	3.2
Dissolved solids	-	43	42.1	5.5	54	30
Iron	Fe	44	347	316	1040	30
Suspended sediments	-	97	15	19.8	151	1
Hardness	$CaCO_3$	45	29.8	4.2	38	21
Calcium	$CaCO_3$	44	9.82	1.3	13	6.6
Magnesium	Mg	44	1.24	0.49	2.4	0.2
Chloride	Cl	43	1.1	1.13	3.9	0
Sulfate	SO_4	45	5.8	1.3	7.9	3.4

* Recorded since 1952 for all parameters except suspended sediments, which were recorded from 1967.

† Units for all parameters except specific conductance and pH are mg/L.

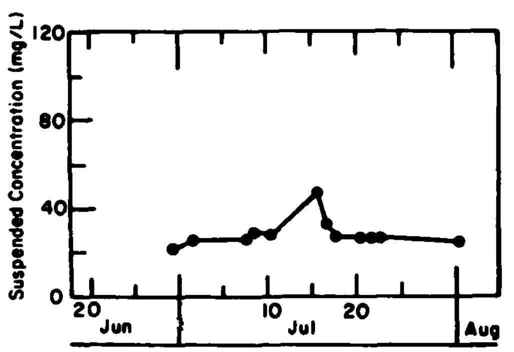


Figure 12. Suspended solids concentrations during the pilot plant study.

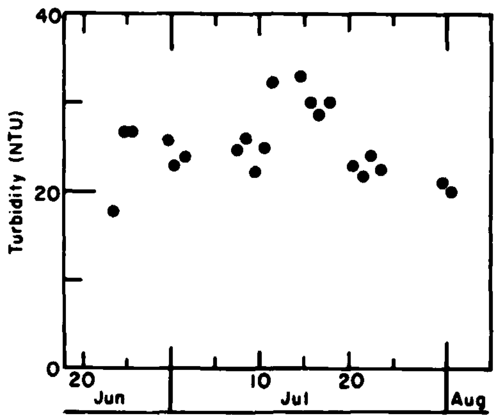


Figure 13. Turbidity during the pilot plant study.

ations of coagulants at various doses were used. Filter loadings from 2.5 to 7.5 gal/min•ft² were successfully tried, with production and backwash requirements varying considerably between runs. The raw water temperature varied between 8.5°C and 14.9°C.

There was a period between 2 and 21 July during which no successful filter runs were accomplished. Runs tried during this period, along with preliminary runs, are summarized in Table 5. Tables 4 and 5 show that raw water turbidity was only slightly higher for the unsuccessful runs (which averaged 25.9 ± 3.67 NTU) than for those considered successful (which averaged 23.4 ± 2.24 NTU) and that the same coagulants and combinations of coagulants at various doses were used. The filter loading was either 2.5 or 5 gal/min•ft² except for one run where 8.4 gal/min•ft² was tried. The raw water temperature was lower overall for the unsuccessful runs, varying between 8.5° and 11.2°C. Because the breakthrough of water containing greater than 1 NTU of turbidity occurred within a half hour of starting a filter run, no production or backwash data were collected and the run was considered unsuccessful.

Data collected during pilot plant testing indicate that conditions for successful and unsuccessful runs were quite similar, with a slight rise in turbidity being the only apparent change. However, near the end of the initial runs in late June, the Soldotna area had a period of above-average rainfall. Discharge data (Fig. 11) confirm that higher-than-average discharge occurred during pilot plant testing, especially at the beginning of July. Suspended solids values were also higher than average during this period (Fig. 12). Apparently, the Kenai River carries a consistent load of glacial silt, which is easily removed. However, high runoff amounts add more silt, which is considerably more difficult to remove. This indicates that although turbidity is a proper parameter to indicate success or failure of a filter run, it is a poor indicator of the "treatability" of the water. The ability to flocculate and treat Kenai River water changed much more than the slight increase in turbidity indicates.

Performance of pilot plant elements

Hydrocyclone

The hydrocyclone was very successful in removing the larger sediment particles (Table 6). The underflow consisted primarily of sand, averaging 390,000 mg/L suspended solids, which concentrated to 63% solids by sedimentation.

Surprisingly, the hydrocyclone removed a larger quantity of total solids than suspended solids (Trans-Alaska Engineering/URS Co. 1979) (Tables 6 and 7). This indicates removal of some filterable residue (Table 8), which is that material capable of passing Whatman GF/C Filter Paper (with an effective retention of 1.2 μm). This unexpected result appears to be correlated with the "treatability" of the raw water, which in turn may reflect the increased proportion of small collodial particles evident in Runs 14-17.

Chemical doses

Three primary coagulant systems were found to be effective during pilot plant testing: alum, alum and lime, and Magnifloc 515C. Lime and alum combined and alum alone were effective in promoting flocculation, regardless of raw water quality; Magnifloc 515C was not.

Alum doses from 5 to 20 mg/L were used; a 10-

Table 4. Summary of successful pilot plant filter runs.

		Pre-filter data							Filter data								Results			
Run and filter no.	Date	Coagulant	Dose (mg/L)	Flocculant	Dose (mg/L)	Raw water flow (gal/min)	Raw water temp. (°C)	Raw water turbidity (NTU)	Loading (gal/min-ft²)	Flow (gal/min)	Clean head loss (ft)	Max. head loss (ft)	Average turbidity (NTU)	Minimum turbidity (NTU)	Maximum turbidity (NTU)	Filter run (hr)	Production (gal/ft²-run)	Backwash (gal/ft²)	Net production (gal/ft²-run)	48-hour production (gal/ft²)
R2 F1	25 June	Alum	10	1849 A	0.25	2.0	N.O.*	27	5	0.55	1.5	5.8	0.6	0.31	7.4	(4)	1200	200	1000	10,200
R2 F2	25 June	Alum	10	1849 A	0.25	2.0	N.O.	27	7.5	0.83	0.83	8.5	0.7	0.44	5.3	(4)	1800	200	1600	16,320
R3 F1	27 June	Alum	10	1849 A	0.25	2.0	N.O.	27	5	0.55	1.0	5.8	0.28	0.20	10.1	7	2100	150	1950	11,307
R3 F2	27 June	Alum	10	1849 A	0.25	2.0	N.O.	27	2.5	0.28	0.6	5.0	0.28	0.18	75.0	27	4050	204	3846	6,809
R4 F1	30 June	M 515C	10	1849 A	0.25	2.0	N.O.	22	5	0.55	1.3	8.9	0.35	0.18	0.51	25	7186	350	6836	12,989
R4 F2	30 June	M 515C	10	1849 A	0.25	2.0	N.O.	22	2.5	0.28	0.7	8.8	0.34	0.16	0.56	44	6600	350	6250	6,818
R6 F1	2 July	M 515C	10	1849 A	0.25	2.0	8.5	24	7.5	0.84	2.3	7.0	0.60	0.43	0.76	12	5400	350	5050	19,947
R16 F1	21 July	Lime Alum	5 20	CA253	0.4	1.0	14.9	23	5	0.55	2.5	8.5	0.49	0.27	0.77	6	1509	145	1346	10,476
R16 F2	21 July	Lime Alum	5 20	CA253	0.4	1.0	14.9	23	3	0.33	0.8	9.0	0.46	0.26	0.80	15	2700	136	2564	8,136
R16 F1A	21 July	Lime Alum	5 20	CA253	0.4	1.0	14.9	23	6	0.66	2.5	7.7	0.37	0.37	0.37	4	1440	150	1290	14,835
R17 F1	22 July	Lime Alum	5 13.3	CA253	0.2	1.0	12.6	22	5	0.55	1.9	9.0	0.48	0.36	0.60	14	3660	317	3342	11,341
R17 F2	22 July	Lime Alum	5 13.3	CA253	0.2	1.0	12.6	22	3	0.33	0.9	9.0	0.60	0.53	0.64	24	4320	158	4161	8,235
R18 F1	23 July	Alum	13.3	CA253	0.2	1.0	13.0	23	3	0.33	0.9	8.5	0.30	0.18	0.57	34	6120	164	5956	8,374
R18 F2	23 July	Alum	13.3	CA253	0.2	1.0	13.0	23	5	0.55	1.2	9.0	0.54	0.26	1.0	30	8269	191	8105	12,913
R19 F1	31 July	Alum	13.3	CA253	0.2	1.0	11.5	21	2	0.22	0.8	8.0	0.28	0.15	0.51	54	1480	200	6280	5,760
R19 F2	31 July	Alum	13.3	CA253	0.2	1.0	11.4	22	6	0.66	1.7	8.5	0.24	0.18	0.36	20	5973	164	5809	13,797
R19 F2A	1 Aug	Alum	13.3	CA253	0.2	1.0	12.0	20	7	0.77	2.0	7.0	0.45	0.21	1.1	12	4947	164	4783	18,734

*N.O.—Data not observed.

Table 5. Summary of unsuccessful pilot plant filter runs.

Run and filter no.	Date	Pre-filter data: Coagulant	Dose (mg/L)	Flocculent	Dose (mg/L)	Raw water flow (gal/min)	Raw water temp. (°C)	Raw water turbidity (NTU)	Filter data: Loading (gal/min-ft²)	Flow (gal/min)	Clean head loss (ft)	Max. head loss (ft)	Average turbidity (NTU)	Minimum turbidity (NTU)	Maximum turbidity (NTU)
R1 F1	23 June	Alum	10	M 515C	0.25	2.0	N.O.*	18	5	0.55	1.3	4.2	5.7	0.36	9.0
R1 F2	23 June	Alum	10	M 515C	0.25	2.0	N.O.	18	8.4	0.92	2.8	4.9	1.6	0.69	2.8
R4 F1	30 June	Alum	5	1849 A	0.25	2.0	N.O.	26	5	0.55	1.5	2.8	9.0	9.0	9.0
R4 F2	30 June	Alum	5	1849 A	0.25	2.0	N.O.	26	2.5	0.28	0.8	0.9	10.0	10.0	10.0
R7 F1	8 July	M 515C	5	1849 A	0.25	2.0	8.5	26	5	0.55	1.4	2.5	5.0	4.2	5.8
R7 F2	8 July	M 515C	5	1849 A	0.25	2.0	8.5	26	2.5	0.28	0.9	1.0	6.1	5.5	6.8
R8 F1	8 July	M 515C	7.5	1849 A	0.25	2.0	8.5	24	5	0.55	1.4	3.0	3.8	2.6	5.0
R8 F2	8 July	M 515C	7.5	1849 A	0.25	2.0	8.5	24	2.5	0.28	0.8	1.5	4.1	2.2	6.4
R9 F1	9 July	M 573C	10	1849 A	0.25	2.0	N.O.	26	5	0.55	1.5	5.5	14.0	14.0	14.0
R9 F2	9 July	M 573C	10	1849 A	0.25	2.0	N.O.	26	2.5	0.28	0.8	0.9	18.0	17.0	18.0
R10 F1	10 July	C 31	5	1849 A	0.25	2.0	N.O.	23	5	0.55	-	8.5	11.0	10.0	12.0
R10 F1	10 July	C31	5	1849 A	0.25	2.0	N.O.	23	2.5	0.28	-	1.4	14.0	12.0	15.0
R11 F1	11 July	Lime	10	1849 A	0.25	2.0	9.5	25	5	0.55	2.0	5.0	9.1	9.1	9.1
R11 F2	11 July	Lime	10	1849 A	0.25	2.0	9.5	25	2.5	0.28	0.7	0.9	11.0	11.0	11.0
R12 F1	14 July	Lime Alum	2.25 3-10	None	-	2.0	10.1	32	5	0.55	1.5	3.1	2.1	1.6	2.6
R12 F2	14 July	Lime Alum	2.25 3-10	None	-	2.0	10.1	32	2.5	0.28	0.5	1.4	1.8	1.0	2.5
R13 F1	16 July	Alum	7	None	†	2.0	9.5	29	5	0.55	2.0	4.0	4.2	1.6	10.0
R13 F2	16 July	Alum	7	None	**	2.0	9.5	29	5	0.55	1.5	2.9	2.7	0.49	6.6
R14 F1	17 July	Alum	7	CA253	0.1	2.0	10.7	28	5	0.55	1.6	2.5	1.8	1.5	2.0
R14 F2	17 July	Alum	7	CA253	0.1	2.0	10.7	28	2.5	0.28	0.8	1.0	1.7	1.2	2.2
R15 F1	18 July	MF 515C	10	1849 A	0.25	2.0	11.2	30	5	0.55	1.1	2.6	4.9	4.9	4.9

* N.O.—Data not observed.
† 0.1 mg/L CA 253 as a filter aid.
**0.1 mg/L CAT FLOC as a filter aid.

Table 6. Suspended solids removal by the hydrocyclone.

Run no.	Raw water suspended solids (mg/L)	Hydrocyclone effluent suspended solids (mg/L)	Suspended solids removed (mg/L)	Suspended solids removed (%)
11	30	24	6	20
13	48	34	13	28
14	32	26	6	18
15	24	18	6	25
16	25	19	6	24
17	27	15	10	40
18	27	18	9	33
19	23	15	8	35
Average	29	21	8	28

Table 7. Total solids removal by the hydrocyclone.

Run no.	Raw water total solids (mg/L)	Hydrocyclone effluent total solids (mg/L)	Total solids removed (mg/L)	Total solids removed (%)
11	-	35	-	-
13	85	72	13	16
14	106	68	38	36
15	96	65	31	32
16	96	62	34	35
17	79	64	15	19
18	70	56	14	20
19	66	58	8	12
Average	85	60	22	24

Table 8. Filterable solids removal by the hydrocyclone.

Run no.	Raw water filterable solids (mg/L)	Hydrocyclone effluent filterable residue (mg/L)	Filterable residue removed (mg/L)	Filterable residue removed (%)
13	37	37	0	0
14	75	42	33	44
15	72	47	25	35
16	71	43	28	39
17	54	48	5	9
18	43	38	5	11
19	43	43	0	0
Average	56	43	14	20

mg/L dose promoted flocculation and provided a filtrate with less than 1.0 NTU turbidity, but the filter runs were generally prematurely terminated by turbidity breakthrough. At a 13.3-mg/L dose, maximum headloss was achieved at about the same time breakthrough occurred, indicating a nearly optimum dose, except when the river was carrying precipitation-induced runoff.

Increasing raw water turbidity required increased alum doses (up to 20 mg/L at 30 NTU) and 5 mg/L of lime as $Ca(OH)_2$ to provide an acceptable quality filtrate. Unfortunately, the raw water quality improved before an optimum dose could be identified. The 20-mg/L alum and 5-mg/L doses with a 30-minute flocculator detention time are known to work, although they are probably excessive.

Magnifloc 515C dosed in the rapid mix chamber was used successfully at 10 mg/L during periods of low turbidity. This dose, with 0.25 mg/L of Magnifloc 1849A as a flocculant, yielded the highest filter production during this study. During periods of high turbidity in both jar and pilot scale tests, Magnifloc 515C would not produce an acceptable floc formation at doses up to 20 mg/L and therefore would not be suitable for full-scale continuous use.

Flocculation

The water of the Kenai River exhibited widely varying flocculation tendencies during testing. During periods of low turbidity, the water flocculated readily at very low mixing energies (GT ≈ 15,000,* Fig. 14). Several successful filter runs (Runs 2, 3, 5 and 6) used this low energy input. As the Kenai River quality changed during mid-July, flocculation required considerably more mixing energy. On 21 July it was necessary to increase GT to achieve a filterable floc. This required that the flocculation time be increased from 15 to 30 minutes, achieved by halfing the flocculator flow. Continually changing river quality made it impossible to determine if all 30 minutes (GT ≈ 90,000) were required; however, this value is known to work, while a 15-minute detention time (GT ≈ 45,000) did not.

Water from the Kenai River became extremely sensitive to mixing energy during periods of higher turbidity. Jar testing and plant operations

*GT = G • T
where GT = mixing energy
G = mixing energy gradient (s^{-1})
T = time (s)

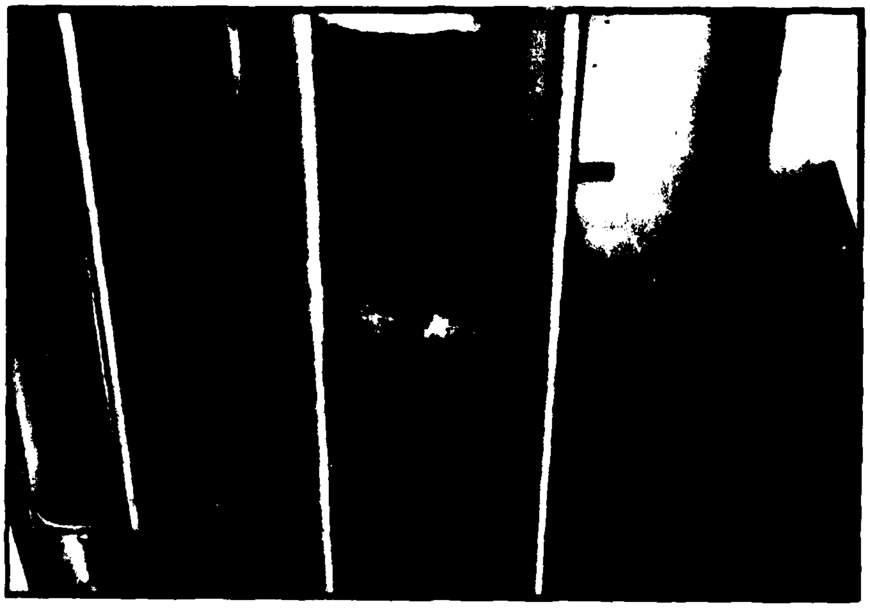


Figure 14. Pinfloc formation suitable for direct filtration.

showed that mixing energy changes from GT = 29,500 to GT = 37,600 caused considerable differences in the floc appearance. However, successful GT values and chemical dosages determined by jar testing didn't always work in the pilot plant. The pilot plant then required more energy, time and alum than the jar tests indicated.

Direct filtration

The filter run data presented in Tables 4 and 5 indicate that direct filtration was capable of producing water containing less than 1.0 NTU of turbidity from natural surface water carrying glacial silt. As previously indicated, higher-than-normal runoff caused some difficulty in achieving favorable results in early July, but a program of jar testing yielded chemical dose and mixing energy information adequate to resume successful filter runs. This practice is similar to that used in full-scale water treatment plants, where a continuous program of jar testing is required to optimize chemical additions. Also, the pilot plant testing took place when natural river conditions were least stable and when the river was carrying large quantities of glacial silt. During the colder months of the year, quality and flow are much more stable (Fig. 11, Table 3). Although treatability and quality declined as flow increased, direct filtration was still possible for all conditions encountered during testing.

Parameters other than effluent turbidity and project costs must be considered before selecting a filtration design. One of the more significant parameters is filter productivity.

Table 4 indicates that different filter application rates and coagulants produced widely varying productivity, run lengths and backwash requirements. This in turn led to considerable variation in the total quantity of water produced by a given set of conditions over a fixed time (48 hours in this study). Generally, lower loading rates resulted in a higher net productivity per run, but not necessarily a greater filter productivity over 48 hours, since the run time may be quite long. For instance, Run 3 on Filter 2 on 27 June (Table 4) had a loading rate of 2.5 gal/min•ft^2 and resulted in a net production after backwashing of 3846 gal/ft^2. However, the filter run time was 27 hours, resulting in a 48-hour production of 6809 gal/ft^2. By contrast, Run 3 on Filter 1 on the same date had twice the loading rate (5 gal/min•ft^2) and yielded a net production of 1950 gal/ft^2. The run length, however, was only 7 hours, resulting in a 48-hour production of 11,307 gal/ft^2.

Generally, higher loading rates result in greater 48-hour productivity. However, no attempt was made to establish an upper limit for loading rates or to determine an optimum chemical dose for high loading rates and filter productivity.

Physical and chemical variables

As stated earlier, turbidity was the main criterion for determining if direct filtration is feasible. Several other water quality parameters were monitored during the course of the study to give further indications of product water quality from a direct filtration treatment plant.

Iron and manganese

The raw water and filter effluents were analyzed for soluble iron with a Bausch and Lomb portable test kit and Mini 20 spectrophotometer. The portable test kit used the 1,10-phenanthroline method specified in Standard Methods (APHA-AWWA-WPCF 1976). All raw water analyses were at or below the limit of detection (0.2 mg/L) except one. All filter effluents were at or below the limit of detection. The drinking water standard for iron is 0.3 mg/L.

Raw water and filter effluent samples were also analyzed for manganese by using the portable test kit and spectrophotometer. No detectable quantities of manganese were found. The limit of detection for this analysis was 1 mg/L.

Alkalinity

The raw water and filter effluents were analyzed for alkalinity by titrating with 0.02 NH_2SO_4 to a pH of 4.5. All raw water alkalinities measured 25 mg/L or less, all in the bicarbonate form. This is very close to the average value of 26.2 mg/L reported for the Kenai by the USGS (Table 3). Lime and alum additions during treatment generally had little effect on the filter effluent.

Calcium and magnesium hardness

Several filter effluent samples were analyzed for hardness by EDTA titration. All samples showed total hardnesses of either 30 or 31 mg/L, which confirms the USGS analysis (Table 3) that the Kenai River water is very soft.

CONCLUSIONS

A direct filtration pilot plant was operated on the Kenai River in Soldotna, Alaska, during the summer of 1980. The purpose of the project was to determine the feasibility of removing streamborne glacial silt using the direct filtration process. A hydrocyclone was used for pretreatment. The filters were multi-media (coal, sand, and garnet), and alum, lime, and several polymers were investigated as primary coagulants and coagulant aids.

The production of water containing less than 1.0 NTU of turbidity was the criterion by which the success or failure of a filter run was measured. Also monitored were total and suspended solids, iron, manganese, alkalinity and hardness.

Turbidities ranged from 18 to 32 NTU in the raw water. Successful filter runs produced water containing less than 1.0 NTU in times ranging from 4 to 44 hours. Suspended solids ranged from 21 to 48 mg/L in the raw water. In the treated water, suspended solids were typically less than 10 mg/L. Iron ranged from less than 0.2 to 1.4 mg/L in the raw water, and was typically less than 0.2 mg/L in the treated water. Alkalinity did not exceed the USGS average of 26 mg/L. Filter application rates of between 2 and 7.5 gal/min•ft² were successful.

The tests of the direct filtration pilot plant on the Kenai River demonstrated that:

1. Direct filtration was successful in treating water from the Kenai River at all water quality levels encountered during the pilot plant testing (18-32 NTU and 21-48 mg/L suspended solids).
2. Changes in the quality of the Kenai River during the study indicate that:
   a. Successful filter runs were not always repeatable.
   b. Turbidity is a poor indicator of the treatability of Kenai River water.
   c. The change in treatability of the Kenai River may be linked to rainfall intensity, which affects the amount of silt in the river.
   d. It was always possible to treat the water encountered during this study by increasing the chemical dose and flocculation time.
3. Hydrocyclones are effective pretreatment devices for removing solids from glacial waters.
4. Filter application rates of up to 7.5 gal/min•ft² are possible, with 48-hour productivity at a maximum at this value.
5. The amount of mixing energy and flocculation time required varies widely with the changes in water quality.

RECOMMENDATIONS

Although the feasibility of using a direct filtration treatment plant was established during this study, further testing is required before designing a prototype. The objectives of further testing would include:

1. Determining the optimum chemical coagulant dose to ensure effective flocculation under varying water quality conditions.

2. Establishing better productivity and backwash requirements by studying the effects of loading rate and flocculation tendencies.

3. Establishing the upper turbidity limit at which direct filtration can successfully operate.

4. Determining which constituent or combination of constituents are most responsible for changes in treatability. This information could prove useful in categorizing other glacial streams with respect to potential treatability by direct filtration.

5. Determining effects of low water temperatures on treatability.

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